Connecting InSAR to a global geodetic datum:
Towards absolute scatterer displacements

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InSAR can be used to estimate double-difference scatterer displacements (in space and in time) based on complex-valued radar reflections stemming from these scatterers. When used in a time-series approach, the double-difference displacements can be generalized to, e.g., single-difference (space-only) velocity estimates, or displacement behavior parameterized via polynomial coefficients. Whatever the parameterization is, a key property is that the estimates are inherently relative. If we focus on changes in elevation (or in the radar line of sight), the estimates are always relative to a reference point with a particular location (or, equivalently, the average of scatterers within a reference area), and a reference epoch. The value assigned to the InSAR reference point can be arbitrary; often, for convenient interpretation of the displacement estimates, a ‘conventional’ value is chosen, e.g. zero displacement or velocity for a reference point situated in an area assumed stable. In these cases the value is deterministic and has zero standard deviation. When InSAR studies use a point or area ‘assumed to be stable’ as reference, the results are subject to this assumption. If the assumption is incorrect, i.e. the reference point is unstable in reality, the other estimates are essentially incorrect as well.

Although effectively all geodetic positioning techniques are relative, there is sometimes the need for InSAR displacement estimates which can be considered to be ‘absolute’, i.e., estimates which can be expressed in a well-defined terrestrial reference frame (TRF) and related to the results of other techniques. In other words, whenever two or more sets of estimates stem from specific reference frames or datums, there is a need for datum connection. For this, the value for the InSAR reference point displacement can be connected to other measurements, e.g. Global Navigation Satellite Systems (GNSS). High-precision geodetic GNSS measurements can be used to derive the ‘absolute’ position (as a function of time) of the InSAR reference point in a global TRF. The displacement of the InSAR reference point in this TRF is then stochastic, and the errors can be propagated. Here we propose such a method for datum connection, to merge the results of InSAR surveys and studies referring to a global TRF with associated noise variance-covariance (VC) matrices, using the existing international or national networks of GNSS stations.

An opportunistic approach for datum connection is to utilize the coherent InSAR scatterers that happen to occur in the vicinity of these GNSS stations as reference points, assuming they show the same displacement behavior as that measured by GNSS. However, this harsh assumption does not always hold in practice, because of local variations in displacements. Also, coherent InSAR scatterers can often result from multiple-bounce reflections, and could contain a component from ambient effects (e.g. swelling/compaction in the surrounding soil) which would not be measured by a well-founded GNSS receiver. Additionally, it is not guaranteed to have coherent InSAR scatterers in the vicinity of a GNSS station.

In the proposed method, we mechanically attach phase-stable radar transponders to GNSS stations. This way, no assumptions are required regarding the relative motion between the transponder and the GNSS receiver, since their sturdy connection ensures that they both experience the same movement. We thus obtain a network of radar beacons with independently
observed position time series in a TRF. As these reference GNSS stations are usually located spatially dense enough to have one or more stations in a typical radar image (170 × 250 km for Sentinel-1), there is an ‘absolute’ InSAR reference point in each scene, connected to a TRF such as the International/European Terrestrial Reference Frame (ITRF/ETRF). The available VC matrices of the GNSS stations can be used when transforming relative InSAR displacement estimates to displacements with respect to the reference ellipsoid. Subsequently, the (time series of) vertical positions can then be referred to an international or national height system using the local state-of-the-art geoid. Existing VC matrices for these geoids can then be used for proper error propagation.

An application of the proposed approach is to tie overlapping or non-overlapping radar datasets together, yielding datasets comparable over large distances, even across oceans and continents. Additionally, region-wide deformation can be linked to sea-level changes via collocated InSAR-GNSS measurements, thereby contributing valuable information, e.g. towards flood risk assessment. Another benefit of this approach can also be the correction for residual orbit errors in different radar datasets. Phase ambiguities can moreover be estimated in an absolute sense, as the connection via the GNSS station yields exact geometric ranges. The collocated transponder-GNSS approach can perform datum connection between InSAR survey results stemming from different satellites and looking directions, simply by programming the transponder accordingly. The regular, standardized and frequent acquisitions of the Sentinel-1 mission will also make the connection of all future radar observations to a TRF possible.

Here we present (i) the mathematical approach for connecting InSAR to a TRF, (ii) experimental results with collocated InSAR-GNSS measurements, and (iii) a feasibility study for the implementation on a national scale, extensible to a European and a global scale. We have performed this study at selected permanent GNSS stations in the Netherlands using Radarsat-2 data. We focus in particular on the case of IJmuiden, with collocated InSAR and GNSS measurements at a tide gauge (Fig. 1). We show an ‘absolute’ displacement map of the area, and discuss in depth the various factors that should be considered for precise datum connection.

Figure 1: A collocated transponder-GNSS installation at the tide gauge in IJmuiden, the Netherlands.